A Study of the Crustacean Zooplankton of Six Floodplain Waterbodies of the Lower Hunter Valley, N.S.W.

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Thirteen species of eulimnetic entomostracans occurred in the waterbodies with *Boeckella fluvialis*, *Calamoecia lucasi*, *Mesocyclops albicans*, *Daphnia carinata* and *Moina micrura* dominant. Momentary species composition averaged 1.8 calanoid species, 1.4 cyclopoid copepod and 2.8 cladoceran species. Numerically, calanoids and cladocerans dominated (42% each). The low number of cladoceran species and the importance of calanoids are unusual in a world context, so possible reasons for these are explored. Most differences between lagoons are explained in terms of relative habitat stability and the presence/absence of predators.

Seasonal variation in total numbers was erratic. All copepods were perennial, *Daphnia carinata*, *D. lumholtzi* and *Bosmina meridionalis* were almost perennial, while the remaining cladocerans were distinctly seasonal. Members of the congeneric pairs *Diaphanosoma excisum* — *D. unguiculatum*, *Daphnia carinata* — *D. lumholtzi*, and *Ceriodaphnia cornuta* — *C. 'dubia'* peaked at different times.

Four of the waterbodies dried periodically, but zooplankton populations recovered quickly on refilling, much faster than the colonization of new sites. Successional sequences depended on season, but generally cyclopoids and *Moina micrura* were fast colonizers, followed by *Boeckella fluvialis*, *Daphnia carinata*, then *Bosmina meridionalis*, and lastly *Calamoecia lucasi* and *Daphnia lumholtzi*.

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INTRODUCTION

Compared with other aquatic communities, the crustacean zooplankton of Australian lakes is relatively well known. There is information on taxonomy and distribution of the major components (e.g. Bayly, 1961, 1964, 1966, 1979, on calanoid copepods; Bayly and Morton, 1978, Morton, 1985, on some cyclopoid copepods; Smirnov and Timms, 1983, on cladocerans), and on the association of species in various areas (Mitchell, 1986; Shiel *et al.*, 1982; Timms and Morton, 1988). Study continues on the value and methodology of conceptualizing associations and on the relative importance of physicochemical and biological factors in determining species composition and seasonal change. Earlier work used and misused the statistic 'momentary species composition' and concentrated on the influence of physiocochemical parameters (e.g. Timms, 1970a), though the role of competition was not completely ignored (e.g. Bayly, 1966: Jolly, 1966). More recently the effect of vertebrate and invertebrate predation has been highlighted (Geddes, 1986; Grant and Bayly, 1981; Reynolds and Geddes, 1984) and new methods devised to depict species composition (Mitchell, 1986).

Most of these interpretations have been based on spot sampling or on short-term studies with some narrow goal in mind. An alternative approach is to monitor plankton over many years and to interpret general trends. Such studies, e.g. Jolly (1966) on the Sydney reservoirs, lack the rigour of specific goal short-term studies, but they can provide useful data. For instance, long-term studies are more likely to record all species at a given site and provide a more accurate assessment of the 'average' plankton community.

Also such studies are able to record in proper context the effect of irregular events such as floods and droughts.

In this paper the crustacean zooplankton of six small floodplain waterbodies of the lower Hunter Valley have been studied monthly for just over 5 years. This period encompassed two droughts and a number of minor floods. With the broadscale distribution of crustacean zooplankters in the region known (Timms, 1970a) and comparative seasonal data available for nearby reservoirs (Timms, 1970b), the aim of this study is to document the long-term composition and variability of plankton in natural sites in mid-eastern Australia and to note the major influencing factors.

Study Sites and Methods

Six floodplain waterbodies of the lower Hunter River near Maitland were sampled monthly from October, 1979 to December 1984. Geomorphically they are blocked valley lakes, but locally they are called 'lagoons', a descriptor used in Australia for any small inland waterbody, so this practice is adopted here. Their location, geomorphic parameters and salient physicochemical features are given in Timms (1987b). Lagoons 1a and 1b contained water throughout the study, and Lagoon 3 was nearly permanent, only drying for 3 out of the 63 months. The other lagoons were intermittently present — Lagoon 2 was dry for a total of 27 months, Lagoon 4 for 26 months and Lagoon 5 for 31 months (see Timms, 1987b: fig. 4). All lagoons filled from their local catchment. On occasions macrophytes grew too extensively to allow open water sampling in Lagoon 3 and less frequently in Lagoon 2.

On each sampling occasion, a conical net 30.5cm in diameter and mesh size 159μm was used to collect zooplankton from open water. If the site was >40cm deep an oblique haul from near the bottom to the surface was taken from a boat, but if the depth was <40cm deep a horizontal tow was taken by wading through the lagoon. In both cases the net was towed at approximately 20cm sec^{-1} for 2 minutes over 25m, thus filtering 1820L at most, but almost certainly much less (Bottrell *et al.*, 1976). The method is semi-quantitative at best, but consistent. Samples were preserved in 5% formalin. Subsamples were taken from each collection so that about 1000 individuals were enumerated. Plankters were assigned to species, though this was incomplete for cyclopoid copepods (small *Mesocyclops albicans* were included with *Thermocyclops decipens* and the latter were lumped with *Eucyclops* spp.). Where two species of calanoid copepod cooccurred, copepodites were included in species totals according to the ratio of adult individuals identified for the species present.

Results

(a) Species Composition and Community Structure

Altogether 13 eulimnetic entomostracans, comprising 3 calanoid copepods, 2 cyclopoid copepods and 8 cladocerans occurred in the 6 lagoons (Table 1). Eight littoral species (2 cyclopoids, 2 ostracods, 3 chydorid cladocerans and *Simocephalus*) sometimes were collected from open waters, but generally in small numbers. *Eucyclops* spp. may have occurred in lagoons other than No. 3, but it is consistent they should be found in the site with the best developed littoral macrophytes. In addition shrimp larvae (?*Paratya australiensis*) occurred in Lagoons 1a, 1b, and 3, mainly in summer, and a number of rotifers, including *Brachionus* spp., *Keratella* sp. and *Asplanchna* sp., were common in summer-autumn. Species composition was similar, but not identical, in each lagoon (Table 1).

The presence of possible plankton predators was also noted. European Carp (*Cyprinus carpio* L.) was common in Lagoon 1b and colonized Lagoon 1a during 1983, but were

TABLE 1

Relative Importance of Entomostracan Zooplankters in the Lagoons

	Species	Lagoons 1a	1b	2	3	4	5
1.	*Diaphanosoma excisum* Sars	3.4	4.3	1.3	4.4	1.6	—
2.	*Diaphanosoma unguiculatum* Gurney	2.8	2.2	0.4	0.6	2.6	1.9
3.	*Moina micrura* Kurz	9.8	12.4	5.2	4.7	9.5	11.2
4.	*Bosmina meridionalis* Sars	2.9	7.7	3.4	2.2	4.4	0.7
5.	*Daphnia carinata* King	14.0	3.6	23.4	6.6	22.3	28.0
6.	*Daphnia lumholtzi* Sars	2.8	5.9	—	2.3	—	—
7.	*Ceriodaphnia cornuta* Sars	3.6	3.6	0.5	3.3	0.3	0.6
8.	*Ceriodaphnia 'dubia'* Richard	2.2	5.2	2.7	5.3	6.7	1.0
9.	Chydorids +	0.2	0.4	1.7	1.1	0.3	0.7
10.	*Simocephalus vetulus elisabethae* (King)	—	—	0.2	—	—	—
11.	*Newnhamia fenestrata* King	—	—	2.0	—	—	—
12.	*Cyprinotus fuscus* Henry	—	—	0.8	—	0.2	1.6
13.	*Boeckella fluvialis* Henry	12.0	8.4	18.7	21.5	14.4	25.7
14.	*Boeckella triarticulata* Thomson	—	—	—	—	—	1.4
15.	*Calamoecia lucasi* Brady	28.1	30.0	17.6	38.7	23.1	10.4
16.	*Mesocyclops albicans* (Smith)	12.0	10.3	15.0	6.4	12.4	11.8
17.	*Thermocyclops decipiens* (Kiefer)	6.2	6.1	7.1		2.2	5.0
18.	*Eucyclops* sp. nov.	—	—	—	3.0	—	—
19.	*Eucyclops* sp. prob. *euacanthus* (Sars)	—	—	—		—	—

* Calculated by averaging percent composition for each month in each lagoon.
\+ includes *Chydorus sphaericus* s.l. O. F. Müller, *Dunhevedia crassa* King, and *Alona diaphana* King.

still not common by December 1984. Mosquito Fish (*Gambusia affinis* Baird and Girard) were numerous in Lagoons 1a, 1b and 3. Notonectids (*Anisops* spp.,) occurred in all lagoons, particularly in Lagoons 2, 4 and 5, and were most common November to April (Fig. 2). No *Chaoborus* were ever caught in plankton tows or in a few Ekman grab samples taken in a benthic study (author, unpublished).

The relative importance of species varied between sites (Table 1). The main differences were between the permanent to near-permanent lagoons (Nos. 1a, 1b, 3) which also had fish and the intermittently-present lagoons (Nos. 2, 4, 5) which lacked fish. *Daphnia lumholtzi* was absent from the latter group and *Calamoecia lucasi*, *Diaphanosoma excisum*, *Ceriodaphnia cornuta*, were less common in them, though the differences may not be significant given the small number of sites. Three species were restricted to these intermittently present lagoons — the ostracods *Cyprinotus fuscus* found in all three and *Newnhamia fenestrata* in Lagoon 2 only, and *Boeckella triarticulata* in Lagoon 5 for just 3 months. On the other hand *Daphnia carinata* was most common in these lagoons. It and *Boeckella fluvialis* were least important in Lagoon 1b in which carp were abundant.

On average the six lagoons contain 1.8 calanoid species, 1.4 cyclopoid species and 2.8 cladoceran species (Table 2). There is seasonal variation in these averages, but it is erratic both between sites (Table 2) and between years (Fig. 1), especially for cladocerans. Of the three groups, however, cladocerans are more consistently present in permanent rather than intermittently present lagoons ($t = 9.5$, $P < 0.001$, DF = 4).

(b) **Seasonality**

Total numbers of zooplankton per month in each lagoon fluctuated *ca*10-100 fold with little apparent seasonal regularity (Fig. 1), but when data were averaged for each month in each lagoon, some general trends emerged (Fig. 2). In all lagoons numbers tended to be lowest in winter and highest in autumn. The two permanent lagoons (1a,

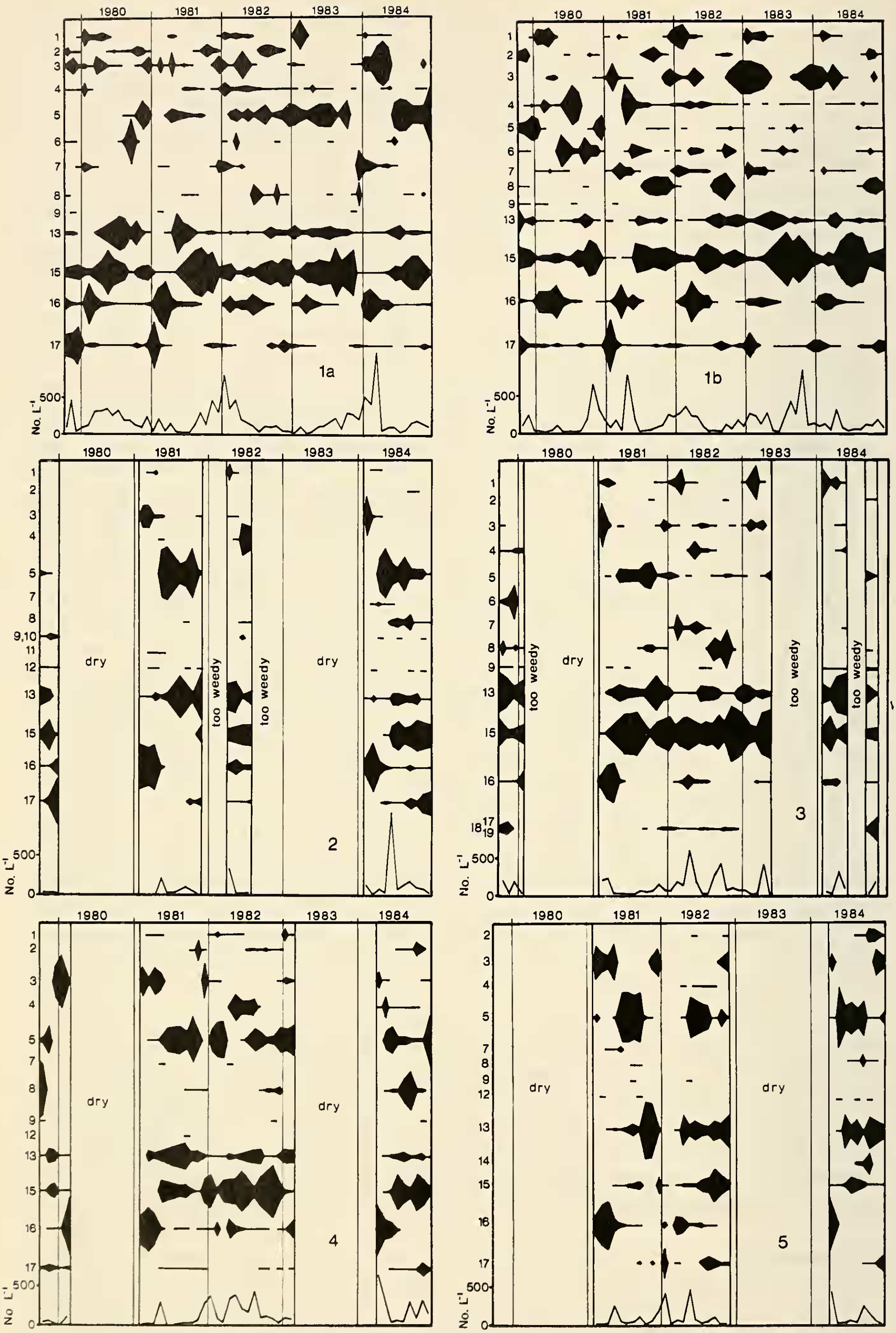

Fig. 1. Relative abundance and approximate total numbers per standardized collection of crustacean zooplankton in the six lagoons (**1a**, **1b**, **2**, **3**, **4**, **5**) for the period October 1979 to December 1984.

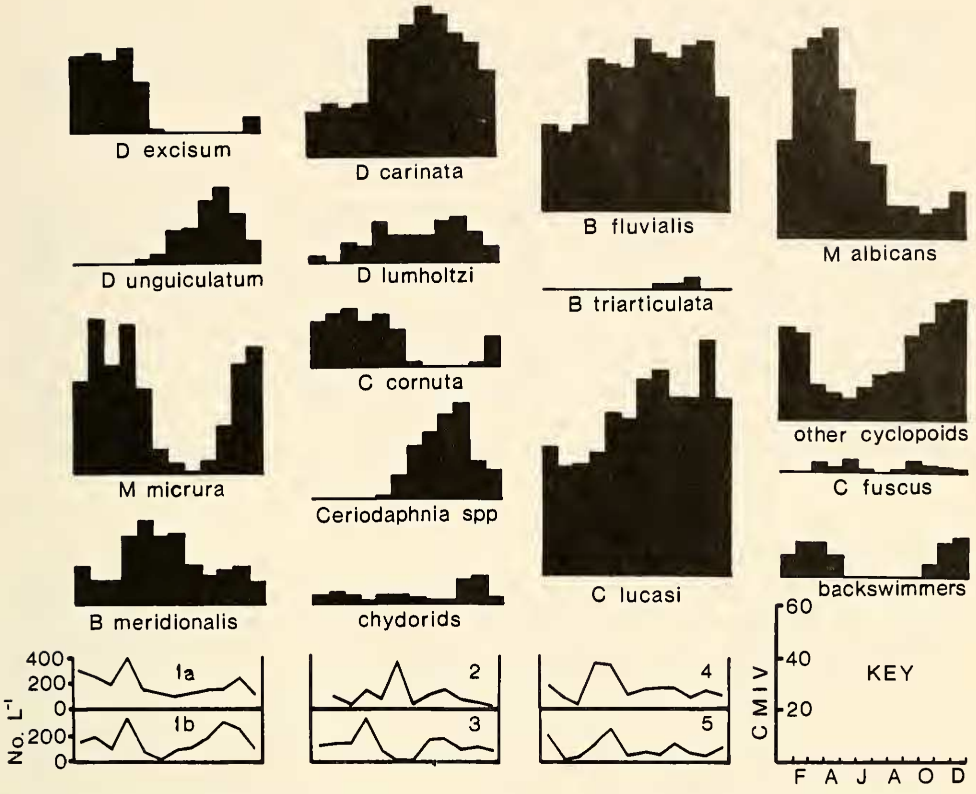

Fig. 2. Seasonal variation in the cumulative monthly importance values (CMIV) of various crustacean species and notonectids for the period October, 1979 to December, 1984. These are derived by giving each monthly occurrence of each species in each lagoon a numerical value (1 = when relative abundance < 2.5%, 2 = 2.5 - 10%; 3 = 10-25%; 4 = 25 - 50%; 5 = >50%) and then summing. Also shown is the average number of zooplankton per standardized collection for each month in each lagoon.

1b) had elevated numbers during October-November and in April. The intermittently-present lagoons (2, 4, 5) had only one major peak in April-June, and the near-permanent lagoon (3) had an intermediate pattern.

Kite diagrams of the percentage abundance of each species over the 63 month study period (Fig. 1) and histograms of cumulative monthly importance values (Fig. 2) show various patterns of seasonality. The calanoids *Boeckella fluvialis* and *Calamoecia lucasi* were perennial, with a period of minimal importance in summer-early autumn, i.e. December to March in *B. fluvialis* and January-April in *C. lucasi*. *Boeckella triarticulata* occurred only from August to October which does not indicate its full seasonal capabilities, as this occurrence is believed to be a failed colonization attempt (see later). Both *Mesocyclops albicans* and *Thermocyclops/Eucyclops* spp. were perennial or almost so (Fig. 2), but with distinct peaks from February to May and from September to February respectively. Three of the 8 eulimnetic cladocerans, *Daphnia carinata*, *D. lumholtzi* and *Bosmina meridionalis* may have been perennial (Fig. 2), though they were not continuously present in any lagoon (Fig. 1). *Daphnia carinata* peaked seasonally in May-October and *B. meridionalis* in April-July. The other 5 species were distinctly seasonal (Fig. 2) — *Diaphanosoma excisum* from January to May, *D. unguiculatum* from July to November, *Moina micrura* from November to May, *Ceriodaphnia cornuta* from December to July, and *C. 'dubia'* from

July to October. Fig. 2 suggests some overlap in the presence of each species in the three congeneric pairs of cladocerans, but this rarely happened in individual lagoons (Fig. 1). Littoral cladocerans tended to stray into open water in any month, but with a peak in spring, and the ostracod *Cyprinotus fuscus* was also recorded in almost any month, except in January, February and July.

(c) Influence of Floods and Droughts

No major river floods occurred during 1979-84, but there were a number of periods of heavy rainfall, local flooding and rapid rises in the levels of the lagoons (Timms, 1987b). No particular effect of these inflows was detected, though in general population peaks occurred in April-May, two months after peak seasonal rainfall.

The lagoons refilled after being dry on 7 occasions, twice each in Lagoons 2, 4 and 5 and once in Lagoon 3 (Fig. 1). Generally the order of response was *Moina micrura* > *Mesocyclops albicans* > *Boeckella fluvialis* $\lessgtr$ *Daphnia carinata*. On one occasion each *Bosmina meridionalis* and *Diaphanosoma excisum* reestablished quickly. *Boeckella fluvialis* typically established sizeable populations a month or so earlier than *Calamoecia lucasi*.

Discussion

(a) Species Composition

Almost all of the species recorded in the six study sites are within their known distribution in northeastern N.S.W. (Smirnov and Timms, 1983; Timms, 1970a). The only exception is *Ceriodaphnia 'dubia'* but re-examination of most of the collections used for Timms (1970a) and (1970b) showed it indeed occurred in a few. More notable are some omissions. *Boeckella minuta* is absent, though common in reservoirs and some natural lakes in mid-eastern Australia, thus confirming its preference for newly-created habitat (Bayly, 1979; Timms, 1970a). *Gladioferens spinosus* is also absent, despite being present in the nearby Hunter River and in local reservoirs which draw their water from it (Timms, 1970b). It seems this species is dispersed almost exclusively through the aquatic medium (Timms, 1970b, 1973), but apparently conditions during major floods when the lagoons are in contact with the Hunter River are unsuitable for dispersal for other reasons.

Of the factors likely to affect species composition and seasonal distribution of crustacean zooplankton, some data are available on the degree of permanence of the lagoons (the major physicochemical difference between them — Timms, 1987b) and on the presence of fish and notonectids. Many differences between the 3 permanent and 3 intermittently-present lagoons (Table 1) can be explained by (a) the relatively poor colonization and recovery ability of *Calamoecia lucasi* (Maly, 1984a; Timms, 1970a, 1987a) and also of *Daphnia lumholtzi* (Timms, 1970a, 1987a) and hence their lesser importance (*C. lucasi*) or absence (*D. lumholtzi*) from the three intermittently present lagoons, and (b) the lagoons being dry when species such as *Diaphanosoma excisum*, *D. unguiculatum* and *Ceriodaphnia cornuta* are normally abundant in lagoons and reservoirs in the area (Fig. 1 and Timms, 1970b).

While no specific data are available on predation by fish in these lagoons, the relatively poor performance of the two largest species, *Daphnia carinata* and *Boeckella fluvialis* in the two lagoons with fish is consistent with the work by Geddes (1986) on zooplankton composition in farm dams, Hume *et al.* (1983) and Straskraba (1965) on carp diets and Lloyd (1986) on the influence of mosquito fish on zooplankton. Also the abundance of predatory notonectids in the lagoons from November to April probably has profound effects on abundances of many species (*cf.* Geddes, 1986). The decline in early summer of *Daphnia carinata* and possibly also of other large species such as *D.*

lumholtzi, *Diaphanosoma unguiculatum* and *Boeckella fluvialis* (Figs 1 and 2) could be explained by predation pressure by notonectids. Seasonal changes in the relative abundance of the smaller species, *Diaphanosoma excisum*, *Moina micrura*, *Ceriodaphnia* spp. and *Calamoecia lucasi* do not coincide with the abundance of notonectids (Fig. 2).

(b) **Seasonal variation**

Erratic seasonal variation in zooplankton numbers as seen in these lagoons is to be expected in small lakes (Pennak, 1949), though there is a trend towards late spring and autumn maxima as seen in larger reservoirs nearby (Timms, 1970b), The perennial occurrence of *Boeckella fluvialis*, *Calamoecia lucasi*, *Mesocyclops albicans* (formerly misidentified as *M. leuckarti* in Australia), *Daphnia carinata* and *Bosmina meridionalis* is consistent with results of other studies in southeastern Australia (Geddes, 1968, 1984: Jolly, 1966; Timms, 1970b: Walker and Hillman, 1977). *Daphnia lumholtzi* is almost perennial in these lagoons, but with a distinct minimal in summer, whereas in nearby reservoirs (Timms, 1970b) it was most abundant in summer and usually absent in winter. Its absence from the 3 shallower ephemeral lagoons studied here and from nearby reservoirs during low water levels (Timms, 1970b), suggests that other factors associated with low water levels may inhibit its development. The seasonal distribution of other species mirror those reported elsewhere in southeastern Australia. *Diaphanosoma excisum* is abundant in summer-early autumn (Timms, 1967, 1970b), *D. unguiculatum* is a spring species (Geddes, 1984; Shiel *et al.*, 1982; Walker and Hillman, 1977), *Moina micrura* blooms in summer (Geddes, 1968, 1984; Shiel *et al.*, 1982; Timms, 1970b) and *Ceriodaphnia cornuta* is also a summer species (Timms, 1970b). No comparative data are available for *Ceriodaphnia 'dubia'.* All species, perennial and seasonal, appear to be multivoltine.

(c) **Community Structure**

Zooplankton community structure is often described by the parameter momentary species composition (MSC), which is the number of species present at any one time (Pennak, 1957). Mitchell (1986) has challenged its value and validity, but most of the inadequacies are due to limited data bases. In the present lagoons this is not a problem as MSCs are based on many observations totalling 32-63 according to lagoon.

The average MSC in the six lagoons (Table 2) is within the range reported for lakes and ponds in southern Australia, though on a world comparative basis the number cladocerans is lower in these lagoons and in Australian sites in general (Mitchell, 1986, Timms, 1970a). In that cladoceran assemblages are less rich in the study lagoons which are intermittently present, perhaps the ephemeral status of many Australian sites contributes to this Australia versus World difference. The explanation for this lies in the distinct seasonality of most cladocerans and hence greater likelihood of their absence from sites which dry intermittently. This also promotes erratic variation in species richness among cladocerans whereas among calanoids community structure is more stable (Table 2). Further study on this factor as well as others mentioned by Mitchell (1986) is needed.

A further method of comparing assemblages is by calculating the average percentage composition of the component species from regular samples taken over at least a year. This is done in Table 1 and has already been used (see above) to highlight similarities and differences between lagoons. Also of interest is the relative overall contribution by cladocerans (42%), calanoids (42%) and cyclopoids (16%) (Table 1). These proportions are not dissimilar from those (36 : 49 : 15 respectively) for Australian lakes reviewed by Mitchell (1986) and provide further evidence for the relatively greater contribution by calanoids in Australia *vis-à-vis* most other countries. Possible reasons for this are partly explored by Mitchell (1986), to which perhaps should be added the apparently great

TABLE 2

Average Momentary Species Composition in the Lagoons

Lagoon	Month												Grand
	J	F	M	A	M	J	J	A	S	O	N	D	Mean
	Calanoida												
1a	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.97
1b	2.0	1.6	1.6	1.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.87
2	–	1.5	1.0	1.7	1.7	1.7	1.7	1.5	1.5	1.7	2.0	1.5	1.59
3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.00
4	2.0	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	1.8	2.0	1.86
5	2.0	0.0	1.0	1.3	2.0	2.0	2.0	2.0	2.0	2.0	1.7	2.0	1.67
All	1.9	1.4	1.5	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.83
	Cyclopoida												
1a	2.0	1.8	2.0	1.8	1.4	1.2	1.2	1.4	1.2	1.6	1.5	1.5	1.55
1b	2.0	2.0	1.8	1.4	1.4	1.8	1.6	1.2	1.0	1.0	1.6	1.8	1.55
2	–	1.0	1.3	1.7	1.7	1.0	1.3	1.0	1.5	1.3	2.0	2.0	1.44
3	1.3	1.3	1.3	1.3	1.0	1.5	1.5	1.0	1.5	1.3	1.0	1.0	1.21
4	1.3	1.3	0.5	1.0	1.3	1.3	1.3	1.3	1.7	1.3	1.3	2.0	1.30
5	2.0	0.5	1.5	1.0	1.0	1.0	1.0	1.7	2.0	0.7	1.0	2.0	1.28
All	1.7	1.3	1.2	1.4	1.3	1.3	1.3	1.3	1.5	1.2	1.4	1.7	1.39
	Cladocera												
1a	3.2	3.6	3.8	3.2	3.4	3.2	3.2	2.8	2.4	3.0	4.0	3.2	3.25
1b	4.0	3.6	3.8	4.8	4.0	3.2	2.6	3.6	4.0	4.2	4.3	3.4	3.83
2	–	2.5	3.0	2.0	3.3	1.7	1.7	1.5	2.5	3.0	3.0	2.5	2.43
3	3.3	2.3	2.5	2.5	2.8	3.0	3.0	3.0	2.7	4.0	3.3	2.3	2.89
4	2.3	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.5	3.2	3.5	2.7	2.43
5	0.0	2.0	1.0	2.0	2.0	2.0	2.0	2.3	2.3	2.0	3.0	2.0	1.88
All	2.6	2.7	2.7	2.8	3.1	2.5	2.4	2.5	2.7	3.2	3.6	2.7	2.79

adaptability and comparatively good dispersal powers of many centropagid copepods in Australia (Bayly, 1964, Maly, 1984a, Timms, 1970a, 1987a).

(d) **Recovery from Dryness**

The succession of species following refilling is broadly similar to that seen in the colonization of an entirely new waterbody (Timms, 1987a). *Moina micrura* and cyclopoids are fast colonizers, followed by *Boeckella fluvialis* and *Daphnia carinata*, then *Bosmina meridionalis* and finally, *Calamoecia lucasi* and *Daphnia lumholtzi*. The exact sequence in any succession is influenced by season. In the present lagoons, if the February and April recoveries are compared, *Daphnia carinata* did better and *Moina micrura* worse in April in accordance with their usual importance in these months (Figs 1 and 2). Also for similar reasons, *Diaphanosoma excisum* did well in one February recovery and *Bosmina meridionalis* in one April recovery. Generally cyclopoids and cladocerans responded quicker to refilling than calanoids, which is explained by the shorter life cycles of the former (Hutchinson, 1967). Of the calanoids, *Boeckella fluvialis* typically responded quicker than *Calamoecia lucasi* to refilling, as it produces more eggs and hence more offspring (Maly, 1984a).

There are two significant differences between the colonization of a new waterbody and recovery in a refilled one. The first is the absence of *Boeckella minuta*, a prime colonizer of new habitats (Bayly, 1979; Maly, 1984a; Timms, 1970a, 1987a). Perhaps it did arrive during recovery (and at other times as well) but was reproductively swamped or competitively excluded by the incumbent *Boeckella fluvialis* (Maly, 1984b). Similar reasons probably account for the failure of *B. triarticulata* to establish in Lagoon 5. The other difference is the greater rapidity of succession in lagoons recovering from dryness. This could be caused by the greater numbers of resting eggs (and hence nauplii hatching) in the recovery lagoon compared with the presumed few dissemules arriving at a new waterbody.

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